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Parameters Involved in the Process of Electrospinning for Photoluminescent Polymer Fibers

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ABSTRACT: Electrospinning is a simple and efficient method for preparing fibers having diameter in the range of micro to nano scale. It uses an electric field between the nozzle and collector; the polymer solution is collected on the surface of the collector screen in terms of the fine fibers. These fibers have wide applications in industries such as composite material, medical, filtration, membrane, textile, etc. In this paper, a review of the electrospinning process, electrospunn photoluminescent polymer fibers, and applications is provided.

KEYWORDS: Electrospinning, Nano fiber, photoluminescent polymers fiber, etc

I. INTRODUCTION

At the end of the 1500s, Sir William Gilbert explained the behavior of electrostatic and magnetic emanation. He found that by affecting the water droplet by an electrostatic field, the water get cone and a long grain-like shape. This forms the first process of electro-spraying. Electrospinning can be viewed as a kind of electro-spraying. In electrospraying, the raw material of is linked to a high voltage power supply to enhance the liquid electrostatic potential. High molecular degree of polymers is used as a raw material due to their intermolecular interaction. The surface charge of liquid and electrostatic potential have a direct relationship; so by increasing or decreasing one of them, the same action will happen for another one. Usually, by surface tension, the volume shape of liquid is deducted. By charging the fluid the surface charge acts in the reverse manner to surface tension, resulting in the fluid changing shape, forming the structure known as the Taylor cone[3].

A Schematic diagram to interpret electrospinning of polymer fibers is shown in figure1. There are basically three components to fulfill the electrospinning process: a high voltage supplier, a capillary tube with a pipette or needle of small diameter, and a metal collector screen. In the electrospinning process a high voltage is used to create an electrically charged jet of polymer solution or melt out of pipette. Before reaching the collecting screen, solution evaporates or solidifies, and is collected as an interconnected web of small fibers [4].

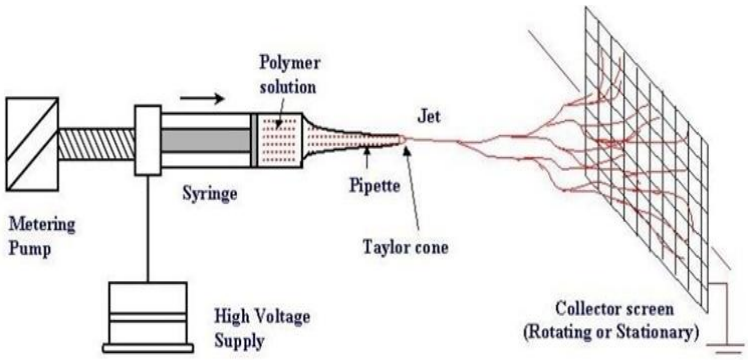

Figure1.Schematic of the Electro-spinning setup

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One electrode is placed into the spinning solution/melt and the other attached to the collector. In most cases, the collector is simply grounded, as indicated in figure. The electric field is subjected to the end of the capillary tube that contains the solution fluid held by its surface tension. This induces a charge on the surface of the liquid. The mutual charge repulsion and the contraction of surface charges to the counter electrode cause a force directly opposite to the surface tension [5]. As the intensity of electric field is increased, the hemispherical surface of the fluid at the tip of the capillary tube elongates to form a conical shape known as Taylor cone [3,6]. The discharged polymer solution jet undergoes an instability and elongation process, which allows the jet to become very long and thin. The solvent evaporates, leaving behind a charged polymer fiber. In the case of the melt, the discharged jet solidifies when it travels in the air.

II. PARAMETERS FOR THE TRANSFORMATION OF POLYMER SOLUTION INTO FIBER

In the following, some of the important parameters have been discussed which influence the transformation of polymer solution into fibers through electrospinning and because of this the study and research is hard.
These parameters includes: i) the solution properties such as viscosity, elasticity, conductivity, and surface tension, ii) Process governing variables such as hydrostatic pressure in the capillary tube, electric potential at the capillary tip, and the gap (distance between the tip and the collecting screen), and iii) ambient parameters such as solution temperature, humidity, air velocity in the electrospinning chamber[7].

A. Viscosity

Solution viscosity plays an important role in determining the fiber size and morphology during spinning of polymeric fibers. It has been found that with very low viscosity there is no continuous fiber formation and with very high viscosity there is difficulty in the ejection of jets from polymer solution, thus there is a requirement of optimal viscosity for electro-spinning. Earlier, also showed that viscosity was important when they electro spun fibers from the melt. The viscosity range of a different polymer solution at which spinning is done is different. Researchers have reported maximum spinning viscosities ranging from 1 to 215poise [1]. This process is conducted at a solution viscosity of poise.

A.1 Conductivity

Polymers are mostly conductive, with a few exceptions of dielectric materials, and the charged ions in the polymer solution are highly influential in jet formation. Solution conductivity is mainly determined by the polymer type, solvent used, and the availability of ionisable salts. It has been found that with the increase of electrical conductivity of the solution, there is a significant decrease in the diameter of the electro spun nanofibers whereas with low conductivity of the solution, there results insufficient elongation of a jet by electrical force to produce uniform fiber, and beads may also be observed. Generally, electro spun nanofibers with the smallest fiber diameter can be obtained with the highest electrical conductivity and it has been found that drop in the size of the fibers is due to the increased electrical conductivity. It was observed that the jet radius varied inversely with the cube root of the electrical conductivity of the solution [1].

A.2. Surface tension

Surface tension, as the function of solvent compositions of the solution, is quite important factor in electro-spinning. They found that different solvents may contribute different surface tensions.

The formation of droplets, bead and fibers depends on the surface tension of solution and a lower surface tension of the spinning solution helps electro-spinning to occur at a lower electric field. However, not necessarily a lower surface tension of a solvent will always be more suitable for electro-spinning [1]. Basically, surface tension determines the upper and lower boundaries of the electro-spinning window if all other conditions are fixed [12].

A.3 Molecular weight

The molecular weights of polymer solution play an important role in the fiber formation during the electro-spinning process. In principle, molecular weight reflects the entanglement of polymer chains in solutions, namely the solution viscosity. Keep the concentration fixed, lowering the molecular weight of the polymer trends to form beads rather than smooth fiber. Increasing the molecular weight, smooth fiber will be obtained [12]. Additionally, the authors also found that as the molecular weight is very high, some patterned fibers can also be obtained at low concentration.
It can be concluded that by lower molecular weight the evaporation rate of the solvent increase, hence, fibers are dry when they deposit on the collector and their shape is more like spherical beads. On the contrary, increasing molecular weight leads to reduce of the evaporation rate and hitting of wet fibers on the collector plate with flat shape. Variations in molecular weight have an influence on fiber diameter, observed a broader range of fiber diameter distribution and increase in average fiber diameter. This could be because of the solution resistance for stretching therefore the molecular weight of the polymer plays a significant role during electro-spinning [1]. This process is conducted at a solution of molecular weight 1:12.

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B. Processing parameters

B.1 Voltage: -

Within the electro-spinning process, applied voltage is the crucial factor. Only the applied voltage higher than the threshold voltage, charged jets ejected from Taylor Cone can occur. It was shown that as the applied voltage was increased from 10 to 15 kV, the fiber diameter was increased, and after that with more increases of voltage, fiber diameters were decreased. At higher applied voltages, the charge could be accelerated so that there is not enough time for the spinning solution to be developed, and thus, the fiber diameter increased as it was observed for the 20-kV applied voltage [1].

B.2 Flow rate: -

The flow rate of the polymer from the syringe is an important process parameter as it influences the jet velocity and the material transfer rate [8]. A lower feed rate is more desirable as the solvent will get enough time for evaporation. There should always be a minimum flow rate of the spinning solution. It has been observed that and the fiber diameter increases with an increase in the polymer flow rate. As shown in figure2. The morphological structure can be slightly changed. Few studies have systematically investigated the relationship between flow rate on fiber morphology and size. Solution flow rate must also be accounted for in the characterization of electro spun fiber morphology. Essentially, solution flow rate adjustments are made in order to maintain a stabilized Taylor cone during electro-spinning. The flow rate was varied as 0.5ml/hr. From the Figure-3 it can be say that the diameter of nanofibers increases with increasing flow rate and beads-free fibers are deposited on the aluminum foil. With minimum flow rate the fibers take more time to deposit on collector and solvent gets evaporates in atmosphere in time period between syringe tip and collector. Due to this, beads-free and smoother nanofibers are collected. As shown in figure2, the main effect plot of mean diameter versus flow rate at each level is as shown in Figure3.

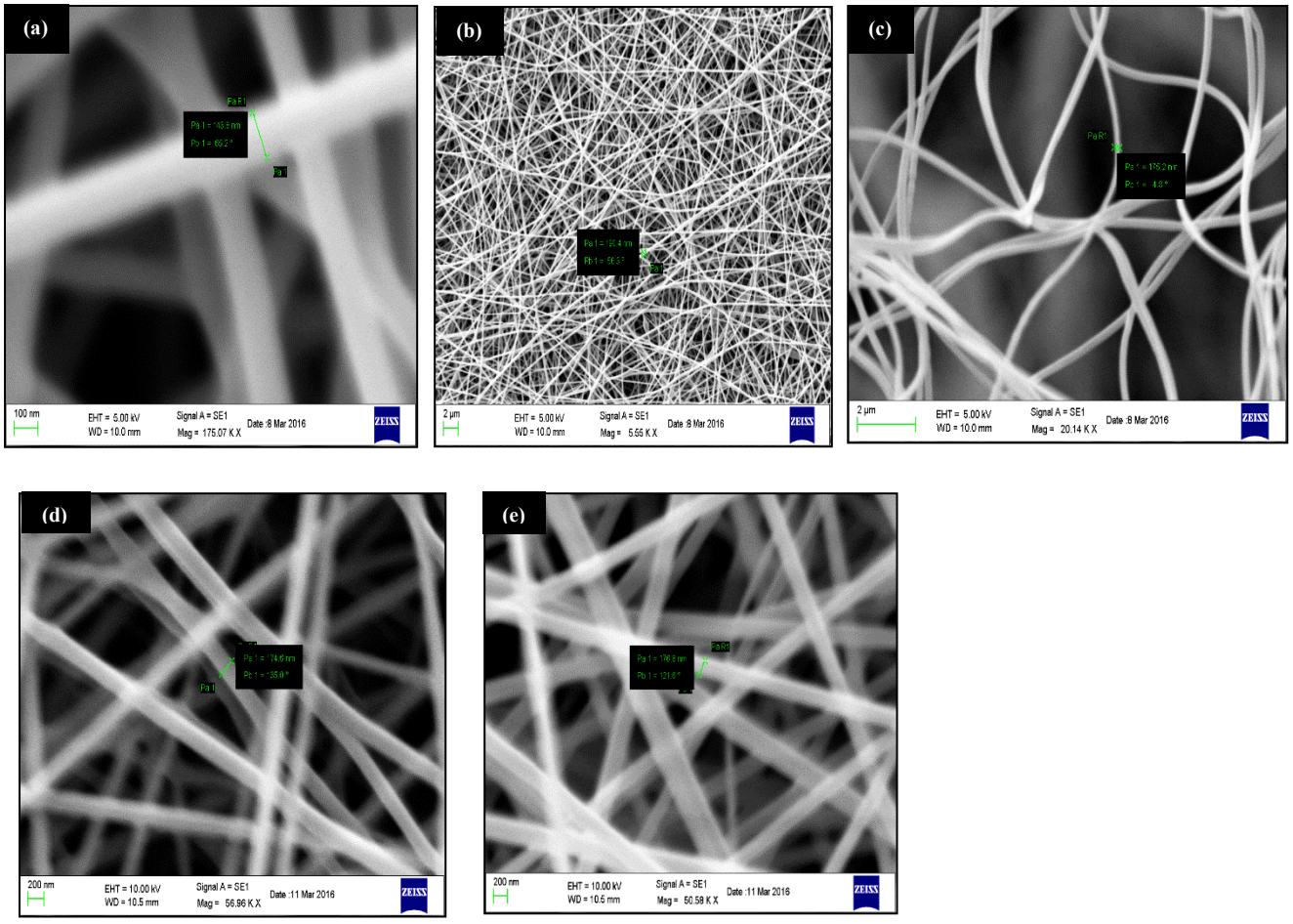

Figure: 2 (a,b,c,d,e) Scanning Electron Microscope images of fibres at different flow rate.

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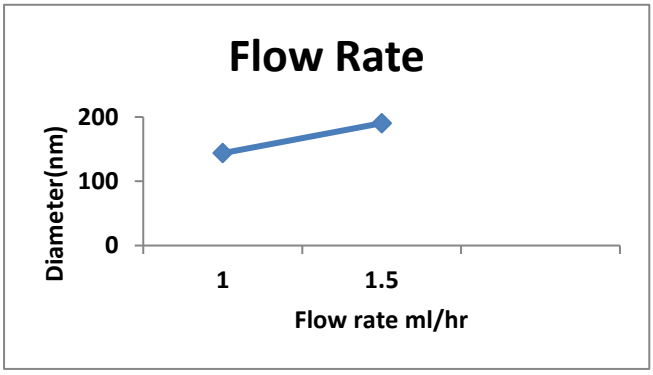

Fig:-3.1 Relationship between the fibre diameter and polymer solution flow rate, showing the avarege fibre diameter for 1.0 ml/hr,1.5. ml/hr in fig a&b. [solution (1:12)& Rotating collector]

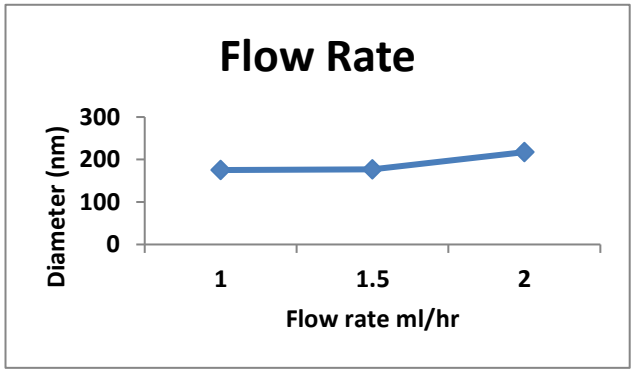

Fig: 3.2 Relationship between the fibre diameter and polymer solution flow rate, showing the avarege fibre diameter for 1.0 ml/hr,1.5 ml/hr,2.0 ml/hr in fig 2 c,d,e.[solution (1:12)& Steady collector]

B.3 Distance between tip to collector

The distance between the tip and the collector has been examined as another approach to control the fiber diameters and morphology. It has been found that a minimum distance is required to give the fiber sufficient time to dry before reaching the collector, otherwise with distances that are either too close or too far, beads have been observed. The effect of tip and the collector distance on fiber morphology is not as significant as other parameters and this has been observed with electro-spinning of PVA [1]. It has been reported that flatter fibers can be produced at 12 cm distances.

C. Ambient Parameters:

It includes the humidity and temperature of the surrounding, which plays an important role in determining the structure of electrospun fiber [9].

C.1 Temperature

In the electro-spinning process, it is found that increase in temperature results in decrease in diameter of the fibers. Also increases evaporation rate. The temperature of solution has both the effects of increasing its evaporation rate and reducing the viscosity of the polymer solution [10]. This process is conducted at an ambient temperature of 32 degree Celsius.

C.2 Humidity

The relative humidity of the spinning environment affects both the morphology of the electro spun fibers and bead formation. The effects of the humidity on spin ability and morphology of the electro spun fibers. When the humidity was kept at or below 50%, stable spin ability was maintained and the obtained fibers showed a random orientation and were free of beads. The surface of the fiber was also smooth and the average diameter was <200 nm. However, when the humidity was above 50% the spin ability was unstable and the fibers showed the presence of many beads and had significantly smaller diameter [11].

III. ELECTROSPUNN PHOTOLUMINESCENT POLYMER FIBERS AND APPLICATION:

Photoluminescent materials have been used for diverse applications in the fields of science and engineering, such as optical storage, biological labeling, non-invasive imaging, solid-state lasers, light-emitting diodes, theragnostic, up-conversion lasers, solar cells, spectrum modifiers, photodynamic therapy remote controllers, optical waveguide amplifiers and temperature sensors. Particular properties of fibers and web like the metric size of the constructing elements, high specific volume and high porosity, endow these products with great potential for medical applications such as drug delivery systems, tissue engineering and medical equipment, wound dressing, cosmetics, functional materials and devices such as composite reinforcement, filters, protective clothing and smart textiles, and energy electronics such as batteries/cells and capacitors, sensors and catalysts. The varied mediums of application allow immeasurable capacity of growth of the photoluminescent polymer phosphors fibers in the area of textile application. The advantages in the properties of polymer phosphors fiber not only improve the aesthetic appeal of the textiles on application but also increase the functionality of the textiles. With the growing lifestyle and expendable income of the present day consumers, the market is primed for growth in application as paints, coatings, prints, vinyl stickers, etc.

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Although some of these applications may be still remained in the laboratory in the current stage, plenty of successful examples have proved that electrospun polymer phosphor fibers have a bright future in a variety of industries.

Yi Xing, et al. [3], highlighted the recent advances of optoelectronic functional fibers in material selection, especially of organic materials, fabrication approaches, as well as their applications in energy conversion, photoelectric sensing, and logical response, and concluded by pointing out the challenges and future research direction in this area.

Monali Bute et al. [6], prepared a Polymer electrolyte membrane based on cellulose acetate/AgTiO2 seems propitious for a lithium-ion battery (LIB) separator due to its superior thermal stability and hydrophilic property. Here, they report the preparation of novel electrospun poly (vinylidine fluoride)/cellulose acetate/AgTiO2 hybrid nanofibers polymer electrolyte membrane by electrospinning for LIB application.

Sangeeta G. Itankar, et al. [4], prepared Eu3+ doped polymer nanofibers fabricated by electrospinning technique using various polymers such as poly(vinylidene fluoride) (PVDF), polyethylene oxide (PEO), poly(vinyl pyrrolidone) (PVP) to study the influence of polymer in their photoluminescence properties. As-fabricated nanofibers were characterized by scanning electron microscopy (SEM), energy dispersive spectroscopy (EDX) and photoluminescence (PL). Spectral analysis of Polymer/Eu3+ nanofibers was based on their emission spectra. The photoluminescence property shows superior bright red emission spectra from the Eu3+ and relatively stronger hypersensitive behavior of the 5D0 → 7F2 transition. Eu3+ doped polymeric nanofibers are very much suitable for photoluminescent fabric designing in smart textiles.

C. N. Pangul et al. [22], prepared samarium (Sm) dysprosium (Dy) co-doped ZnO nanofibers for colour-tunable photoluminescence. The prepared nanofibers were characterized by SEM, EDX, XRD, UV-Vis and FTIR. Nanofibers' diameter and morphology was studied through SEM and the diameter was found to be in the range of 100–180 nm while the presence of elemental ZnO, Dy and Sm was assured by EDX spectrum. XRD study reveals the crystalline structure, while the presence of metal stretching bond of ZnO was observed around 450 cm−1 in FTIR studies. A tremendous enhancement in band gap was observed by UV-Vis spectrum. Photoluminescence spectra clearly depict the energy transfer mechanism within the host ZnO and dopants Sm and Dy wherein CIE parameter confirms the colour tunability of co-doped ZnO nanofibers. Such materials can be a very good optimum candidate for colour tunable luminescent light-emitting fabrics.

IV. CONCLUSION

Electrospinning is simple and promising method for preparing the fibres. It uses electric field between nozzle and collector. Photoluminescent polymer fibre which embroidered on the clothes attracts more attention as compared to ordinary clothes. Polymeric nanofibers are very much suitable for photoluminescent fabric designing in smart textiles. These fibres with long afterglow luminescence can find application in interior decoration, intelligent ceilings, night indicators, or luminous logos and have wide applications in industries such as composite material, medical, filtration, membrane, textile, materials labels etc. In summary, we have reviewed the electrorspun photoluminescent polymer fiber and nanofiber's applications due to their biocompatibility, non-toxicity, and flexibility in potential applications in various fields.

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